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TECHNOLOGY DEMONSTRATION OF SINGLE HYDRAULIC FLUID FOR ARMORED GROUND VEHICLE SYSTEMS

INTERIM REPORT
BFLRF No. 298

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The primary hydraulic fluids used today by the U.S. Army are MIL-H-6083 and MIL-H-46170. MIL-H-6083 is a petroleum-base, low flash point fluid, and MIL-H-46170 is a synthetic fluid with a higher flash point but extremely high viscosity at lower temperatures. This new fluid, referred to as single hydraulic fluid (SHF), is a synthetic-base fluid with improved flammability and low-temperature viscosity characteristics. This report discusses the SHF characteristics, laboratory evaluations, and initiation of pilot field demonstration and preliminary results.

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EXECUTIVE SUMMARY

Problems and Objectives: The primary hydraulic fluids used by the U.S. Army today are MIL-A-6083 and MIL-H-46170. MIL-H-46170 was developed in the 1970s as a replacement for MIL-H-6083, which was considerably more flammable, at least as determined by flash point. However, since MIL-H-46170 is much more viscous at –40°C, certain applications required the continued use of MIL-H-6083. An example of this is the M-109 self-propelled howitzers.

Importance of Project: The importance of this program is that, if successful, the U.S. Army will have an option to use a hydraulic fluid that has good low-temperature properties and is less flammable. A secondary benefit is that the inventory can be reduced from two fluids to one fluid, also eliminating the possibility of putting the wrong fluid in certain vehicles.

Technical Approach: Laboratory and field testing is being conducted in order to verify that the fluid meets the proposed specifications and that these specifications provide adequate performance in actual vehicles in normal field training operations. Monitoring of vehicles in the field that have had the prescribed fluid replaced with the test fluid will continue for one year.

Accomplishments: Chemical analysis, flammability, corrosion, and wear testing have been conducted on the new fluids and the fluid samples taken at time of changeover to the new fluid. Field evaluations of the single hydraulic fluid (SHF) are under way, and the first quarter of operation is completed. Field exercises and live round firings have been conducted with no observed problems.

Military Impact: It is expected that this demonstration will provide the U.S. Army with an acceptable replacement for two currently used hydraulic fluids, improving the shortcomings of each fluid. No major problems are expected.

FOREWORD/ACKNOWLEDGMENTS

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I. INTRODUCTION

Currently, the U.S. Army has two different military specification hydraulic fluids that are used in the armored ground system, each with its benefits and shortcomings. One of these fluids is a hydrocarbon-based fluid, MIL-H-6083; the other is a polyalphaolefin synthetic fluid, MIL-H-46170. The development of a new fluid to replace both fluids would be beneficial not only from a logistic standpoint, but this new single fluid would also have improved capabilities in relation to the flammability of MIL-H-6083 and the low-temperature thickening of MIL-H-46170. This technology demonstration program has been designed to evaluate the single hydraulic fluid (SHF) candidates and is being conducted in two phases, i.e., the laboratory analysis and the field evaluations. These two phases are discussed separately in the report.

II. LABORATORY ANALYSIS

A. Test Fluid Properties

The hydraulic fluids used in this program are shown in TABLE 1 where the key properties are summarized and compared against specification requirements. Laboratory testing was conducted on two candidate SHF samples from different suppliers. These fluids are identified as Test Fluid A and Test Fluid B. The pilot field demonstration was conducted only on Test Fluid B.

B. Analytical Procedures

In support of the goal to find a single replacement fluid, a limited series of tests was conducted to determine the overall suitability of candidate replacement fluids.

TABLE 1. Technology Demonstration Fluid Properties

	SHF (Proposed)	Test Fluid B	MIL-H-46170	MIL-H-6083
Pour Point, D 97, °C	–60 min	–54	<–56	<–60
Viscosity, D 455, as follows:				
40°C, cSt	8 min	9.3	15.8	13.70
100°C, cSt	2.5 min	2.7	3.8	4.6
–40°C, cSt	800 max	744	2,550	715
Acid Number, D 664, mg KOH/g	Report	0.22	0.14	0.14
Flash Point, D 92, °C	180 min	166	224	110
Fire Point, D 92, °C	190 min	200	252	121
Water Content, D 1744, wt%	0.01 max	0.02	0.05	0.03

1. Flammability Testing Procedures

A series of flammability test procedures was conducted on the candidate samples of SHF to determine, in back-to-back comparisons, their flammability characteristics and properties. The series of flammability test procedures incorporated both standard and nonstandard tests. Each test procedure is discussed in more detail in the following subsections.

a. Flash Point, Fire Point, ASTM D 92, Cleveland Open Cup

This test method is designed for use on petroleum products with a flash point above 79°C (175°F). The procedure requires a test cup to be filled to a specified level with the test fluid. The temperature of the test fluid is gradually increased while a small test flame is intermittently passed across the top of the cup. The lowest temperature at which the vapor is ignited by the flame passing over the surface is designated as the *flash point*. This test procedure is conducted in a Cleveland Open Cup apparatus as specified by the ASTM test procedure. The fire point is obtained by simply continuing to heat the sample until burning is stabilized above the liquid surface. This value is typically 20° to 40°F above the flash point.

b. Autoignition Temperature, ASTM E 659

This test procedure determines the hot- and cool-flame autoignition temperature of a liquid chemical in air at atmospheric pressure in a uniformly heated glass vessel. The standard test procedure, conducted in a special apparatus developed to ensure lab-to-lab repeatability, specifies that a 500-mL glass flask be heated uniformly in a circular heating enclosure. When the flask has been heated to the specified temperature, small amounts of sample are injected into the vessel. *Autoignition* is evidenced by the sudden appearance of a flame inside the flask and an increase in temperature of the gas mixture. Ignition delay times (ignition time lags) are measured in order to determine the ignition delay-ignition temperature relationship.

c. Flame Propagation

As outlined in specification MIL-H-83282B, this procedure measures the relative flame propagation of low-volatility liquids such as hydraulic fluids. A ceramic fiber cord saturated by the test fluid is stretched over two holders and ignited. The rate at which the flame travels across the string is measured and reported in centimeters per second. To qualify as an acceptable hydraulic fluid, the propagation rate should not be more than 0.30 cm/sec.

d. Hot-Surface Ignition

Hot-surface ignition experiments use an apparatus described in Federal Test Standard 791C Method 6053. This procedure utilizes a section of 7.6-cm (3-in.) diameter stainless steel pipe heated from the inside by a carborundum resistance heating rod. This test procedure is designed to simulate the response of a fluid spilled onto a heated manifold such that may be found as part of an engine system. The fluid is applied to the heated surface of the tube in a controlled manner using a Graham pump. During this test procedure, variables known to affect the hot-surface ignition, e.g., air velocity and temperature, are kept constant to allow back-to-back evaluations on an equal basis.

e. High-Pressure Spray Ignition

High-pressure atomization spray ignition studies are conducted using a nitrogen-pressurized cylinder and an atomizing nozzle. An oxy-acetylene torch inserted into the mist spray serves as the ignition source. This procedure is intended to simulate a leak in the high-pressure hydraulic fluid system. Realistically, a leak would not, in most cases, produce a mist similar to an atomizing nozzle; therefore, it is believed that this test is a severe evaluation of comparative mist flammability. Viscosity, fluid temperature, surface tension, and system pressure are parameters affecting mist formation, thus, these considerations were incorporated into this test procedure.

f. Ballistic Testing

This test procedure, developed at Belvoir Fuels and Lubricants Research Facility (BFLRF) several years ago, is considered to be a small-scale but severe procedure to evaluate fluid flammability. The test procedure utilizes a steel cylinder approximately 10.2-cm × 76.2-cm high (4 × 30 in.) containing 2 liters of fluid, which would fill the cylinder approximately one-half full. The ignition source is a 20-mm High-Explosive Incendiary Tracer (HEIT) round. A steel rack holds the test cylinder in a vertical position. The 20-mm round is fired at the center of the cylinder in order to strike the target at the fluid-air interface. A schematic of the test facility is shown in Fig. 1. The ballistic impact is recorded on video and 16-mm Hicam at 500 frames per second. Results generally included a large mist fireball and residual pool burning for lower flash point fluids.

2. Oxidation-Corrosion Stability

This method is used for testing an hydraulic oil to determine its ability to resist oxidation and its tendency to corrode various metals. The metal specimens are immersed for 168 hours in a bath set at 121°C (250°F). Weight loss for the metal specimens is determined, and acid number and viscosity changes are determined for the fluid.

3. Hydraulic Pump Endurance Testing

Constant volume vane pump comparative testing was conducted on SHF using MIL-H-6083 and MIL-H-46170 as comparative reference fluids. For this testing, a constant-volume, high-pressure vane pump test procedure, ASTM D 2882-90, was followed. This procedure is routinely used for indicating the wear characteristics of petroleum and nonpetroleum hydraulic fluids.

As outlined in this procedure, 3 gallons of hydraulic fluid are circulated through a rotary vane pump system for 100 hours at a pump speed of approximately 1,200 rpm and a pump outlet pressure of 2,000 ± 40 psi. Fluid temperature is maintained at 150° ± 5°F for these fluids being tested.

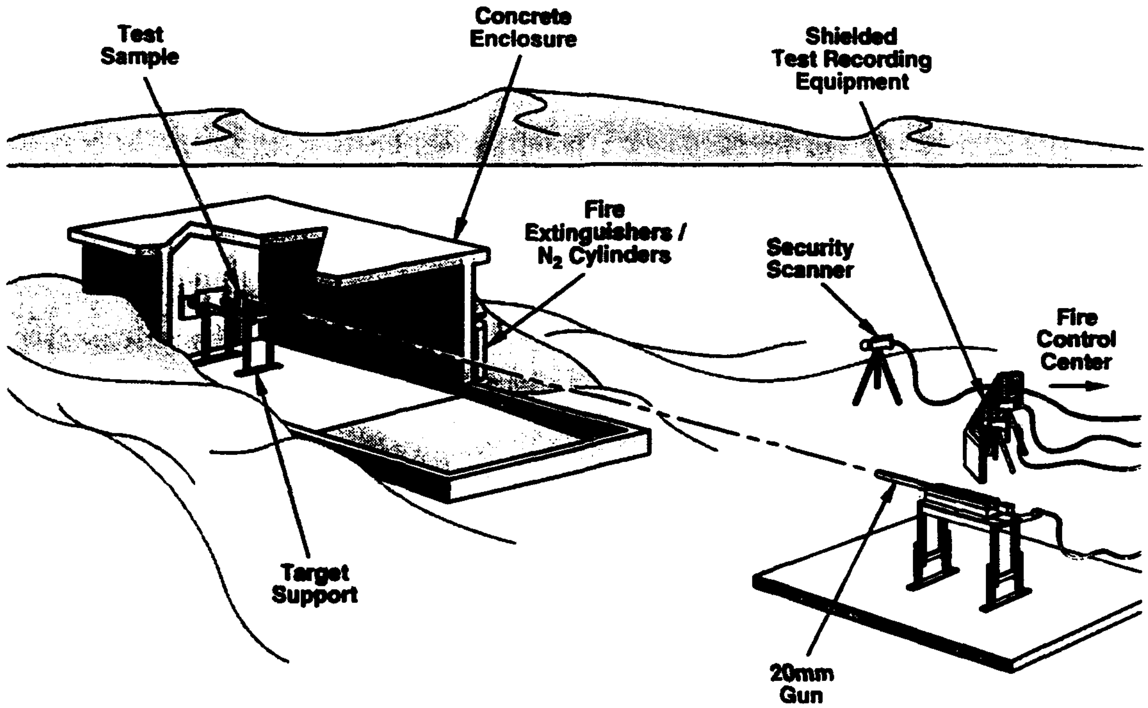

Figure 1. Schematic of BFLRF test facility

4. Laboratory Wear Testing of Single Hydraulic Fluid

Previously, BFLRF has defined the oxidation, corrosion, and wear characteristics of hydraulic fluids from different base stocks, including petroleum, CTFE, Silicone, and the standard PAO fluids qualified under MIL-H-46170. The objective of the present work is to define the oxidation, corrosion, and antiwear resistance of SHF in comparison to the remaining widely used, well-characterized hydraulic fluids.

C. Results and Discussion of Laboratory Testing

1. Flammability Testing

This series of flammability tests is intended to measure a broad spread in flammability characteristics among the tested fluids. These results are caused not only by chemical composition but also, in some cases, by physical characteristics such as viscosity. The results obtained from these series of tests and the BFLRF interpretation of these results are discussed below.

TABLE 2 presents test results obtained from back-to-back comparative testing of the listed samples. These results show that the petroleum-based MIL-H-6083 ignites more readily than MIL-H-46170 and probably presents the most severe fire hazard of the fluids tested.

Flame propagation test results (see TABLE 3) illustrate a reduced flammability hazard with SHF fluids over the specification hydraulic fluid MIL-H-6083. These tests are affected both by chemical composition and physical properties. The test string is saturated with the fluid to be tested and ignited with an ignition source. Travel time of the flame front is recorded in cm/sec and may correlate with flame propagation over a pool of spilled fuel. MIL-H-83282 hydraulic fluid specification allows up to 0.3 cm/sec.

TABLE 2. Standard Flammability Test Results

Fluid	Flash Point, D 92, °C	Fire Point, D 92, °C	Autoignition, ASTM D 659, Temp., °C/Time, sec
1. Test Fluid A	168	200	365/ 6.6
2. Test Fluid B	166	200	356/ 7.8
3. FRH — MIL-H-46170	220	--	363/ 2.2
4. Hydraulic Fluid — MIL-H-6083	126	--	243/73.5

TABLE 3. Flame Propagation

Fluid	Propagation Rate, cm/sec
1. Test Fluid A	0.20
2. Test Fluid B	0.19
3. FRH — MIL-H-46170	0.23
4. Hydraulic Fluid — MIL-H-6083	0.95

Hot-manifold ignition studies indicated that hot-surface ignition will occur with all the test fluids, and the temperatures required for ignition are not greatly different among the various fluids. An interesting result observed was that the lower flash point MIL-H-6083 required 44° to 56°C (80° to 100°F) increase over the synthetic MIL-H-46170 hydraulic fluid. These results had been noted previously and are believed to be attributed to the higher volatility of MIL-H-6083, which caused a vapor-rich layer over the surface of the ignition source. This factor indicated higher energy levels are required for ignition. TABLE 4 summarizes the hot-surface ignition results.

TABLE 4. Hot-Surface Ignition

Fluid	Hot-Surface Ignition,°C
1. Test Fluid A	556
2. Test Fluid B	542
3. FRH — MIL-H-46170	504
4. Hydraulic Fluid — MIL-H-6083	546

High-pressure spray, which uses an oxy-acetylene torch ignition source, was used to evaluate the relative mist flammability characteristics of the test fluids. The fluid was atomized using a hollow cone atomizing nozzle and 6895-kPa (1000-psi) nitrogen pressure. The oxy-acetylene torch flame was inserted directly into the mist and moved to different distances from the nozzle. The results of these tests are reported in TABLE 5.

TABLE 5. High-Pressure Spray Ignition

Fluid	Results
1. Test Fluid A	Ignition, No Sustained Burning
2. Test Fluid B	Ignition, No Sustained Burning
3. FRH — MIL-H-46170	Ignition, No Sustained Burning
4. Hydraulic Fluid — MIL-H-6083	Ignition, Some Sustained Burning

Ballistic testing was conducted in order to provide a more severe evaluation, somewhat representative of battlefield conditions. Results obtained from reviewing the video recording are summarized in TABLE 6 and indicate that all of the fluids ignited readily and formed a large mist fireball. Some of the fluids sustained burning. These tests demonstrated, realistically, the hazard caused by hydraulic fluid being ignited by a ballistic penetration. It should be noted that this fireball essentially filled the approximately 22.7 m^3 enclosure when only 2 liters of fluid were tested.

TABLE 6. Ballistic Flammability Evaluations

Fluid	Mist Fireball	Sustained Burning
1. Test Fluid A	Yes	No*
2. Test Fluid B	Yes	No*
3. FRH — MIL-H-46170	Yes	No
4. Hydraulic Fluid — MIL-H-6083	Yes	Yes

* Some sustained burning in one of the duplicate tests.

2. Oxidation-Corrosion Stability

Results of the oxidation-corrosion testing, which are presented in TABLES 7 and 8, indicate that these two fluids have acceptable oxidative-corrosive characteristics with minimal viscosity and acid number changes. The most important result is the effect on the metal surface, which had acceptable metal loss with no change on the surface finish.

3. Hydraulic Pump Endurance Testing

Results of the wear testing conducted on MIL-H-6083, MIL-H-46170, and SHF are presented in Appendices A, B, and C. These results were obtained using ASTM D 2882-90 test procedure and are totally inconclusive. Even though the procedure does not prescribe a minimum viscosity, it is believed that these fluids are all below the actual acceptable limits since the pressure and temperature could not be controlled according to the prescribed procedure.

The only reference to temperature and viscosity in this procedure is the requirement that fluids with a 40°C viscosity of 46 cSt or less be tested at 65.6°C, and fluids with increased viscosities tested at 79.4°C. Therefore, the wear loss results reported for these fluids, even though there is some directional value, cannot be reported as acceptable test results.

TABLE 7. Results of Oxidation-Corrosion Testing on Test Fluid A

Test Started 07-19-93
Test Ended 07-29-93

Temp, °F 121 (250)
Test No. & Cell No. 1-1

Test Hrs	Viscosity at 40°C	Viscosity Increase, %	TAN
0	9.34	--	0.36
168	9.39	0.54	0.76

Oil Loss % 0

Metals	Wt Δ mg/cm^2	Appearance
Cd	−0.01	No Change
Steel	+0.01	No Change
Mg	0.00	No Change
Cu	0.00	No Change
Al	0.00	No Change

Test Cell Appearance

Clean above and below oil level

TABLE 8. Results of Oxidation-Corrosion Testing on Test Fluid B

Test Started 07-19-93
Test Ended 07-26-93

Temp, °F 121 (250)
Test No. & Cell No. 1-2

Test Hrs	Viscosity at 40°C	Viscosity Increase, %	TAN
0	9.33	--	0.21
168	9.41	0.86	0.60

Oil Loss % 0

Metals	Wt Δ mg/cm^2	Appearance
Cd	−0.01	No Change
Steel	+0.01	No Change
Mg	−0.01	No Change
Cu	−0.07	No Change
Al	0.00	No Change

Test Cell Appearance

Clean above and below oil level

4. Lubricity and Wear

Oxidation and corrosion tests have been completed with the SHF according to ASTM D 4636. In general, the stability of the SHF was marginally lower than that of the previously tested oil qualified under MIL-H-46170 and appreciably lower than that of silicone-based fluids (MIL-B-46176), resulting in some copper corrosion at very high temperatures. However, it should be noted that some of the test conditions were relatively severe, and the SHF had better stability than petroleum-based hydraulic fluid qualified under MIL-H-6083.

Wear tests were performed using the Cameron-Plint wear test apparatus, as well as the four-ball wear test (ASTM D 4172). The Cameron-Plint apparatus was used in most of the tests, as it allows use of various metallurgies and a very wide range of contact conditions. In general, the SHF fluid produced increased wear compared to the regular MIL-H-46170 oil. This variation was apparent over a wide range of speeds and loads, and so is probably not due to its reduced viscosity. However, it should be recognized that the SHF has similar friction and wear characteristics to petroleum (MIL-H-6083) and CTFE (MIL-H-53119) based fluids and has appreciably better lubricity than silicone fluid. In general, directionally similar results were observed in the four-ball apparatus, as summarized in TABLE 9.

The Cameron-Plint apparatus has been modified to allow wear tests to be performed at low temperatures. A refrigerated ethylene glycol-filled fuel reservoir base was machined and will allow testing down to –20°C. Wear tests will be performed under cold conditions using the SHF as well as CTFE, petroleum, PAO, and silicone-based fluids for comparison. These results should be available in the near future as scheduling requirements allow. The complete set of test data for the SHF will then be assembled into the existing final report, which details the oxidation and wear characteristics for all the test oils.

TABLE 9. Results of Four-Ball Wear Tests Performed According to ASTM D 4172

Fluid Specification No.	Wear Scar Diameter, mm
MIL-H-6083	0.64
MIL-H-46170	0.38
MIL-H-46170 (LT SHF)	0.58
MIL-B-46176	1.75
MIL-H-53119	0.61
Dow Corning Silicone	2.10

III. FIELD DEMONSTRATION

A draft SHF pilot field demonstration plan for Ft. Bliss, TX (Appendix D) was staffed through Belvoir RD&E Center at Ft. Belvoir, VA, and the Command Staff and Regimental Maintenance Management Center of the 3rd Armored Cavalry Regiment (ACR) at Ft. Bliss, TX. Copies were provided to the Deputy Director for Logistics, Directorate of Installation Support, and the U.S. Army Materiel Command Logistics Assistance Office at Ft. Bliss, TX. The single hydraulic field demonstration is planned for a 1-year duration. The purpose is to demonstrate acceptable field performance of combat-tracked vehicles using the single hydraulic fluid in lieu of petroleum-based MIL-H-6083 hydraulic fluid and synthetic-based MIL-H-46170 fire-resistant hydraulic fluid.

A. Approach

BFLRF staff members met with U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) and the U.S. Army Munitions, Armament, and Chemical Command (MACCOM) logistics assistance representatives (LARs) to discuss the planned method of fluid conversion in turret and recoil hydraulic systems in selected M1A1 Main Battle Tanks, M3A2 Cavalry Fighting Vehicles, and M109A2 Self-Propelled Howitzer combat vehicles. The M3A2 fighting vehicle, however, was dropped from consideration when it was learned that the turret is electrically powered and that the only hydraulic component is the rear ramp door which, if necessary, can be opened and closed manually. BFLRF staff members, accompanied by TARDEC and MACCOM LARs, visited the units tasked to provide the test and control vehicles to study the hydraulic systems and to decide on the type of equipment and methodology needed to accomplish the fluid conversions on the test vehicles.

B. Details of Demonstration

1. Test Vehicles

The test vehicles were selected by local organizations tasked to support the demonstration. Six M1A1 tanks and six M109A2 Howitzers were selected by both the 1st and 2nd squadrons of the 3rd ACR. Of the 24 vehicles selected, 12 were designated as control test vehicles for comparison. The hydraulic systems on the vehicles were checked for proper operation and leaks. The vehicles participating in the Single Hydraulic Demonstration Program are given in TABLE 10.

2. Test Hydraulic Fluids

Only Test Fluid B was used in the test vehicles. The MIL-H-6083 and MIL-H-46170 lubricants used in the control vehicles were obtained through Army supply channels. The SHF-proposed requirements and the MIL-H-6083E and MIL-H-46170B requirements are given in TABLE 11.

3. Fluid Conversion Methodology

a. M109A2 Self-Propelled Howitzers

Prior to draining the hydraulic fluid, the vehicles were warmed up and the hydraulic systems were exercised. The systems were depressurized and the hydraulic fluid drained from the

TABLE 10. 3rd ACR Vehicles Participating in the MIL-H-41670 Single Hydraulic Fluid (SHF) Demonstration Program at Ft. Bliss, TX

Vehicle No.	Vehicle Type	Serial No.	Test (T), Control (C)	Miles	Hours	Unit	In-Program Date
HOW-12	M109A2	5324	T	567	78	2nd Sqd.	28 Jun 93
HOW-15	M109A2	2893	T	532	52	2nd Sqd.	30 Jun 93
HOW-16	M109A2	2132	T	2,822	199	2nd Sqd.	01 Jul 93
HOW-13	M109A2	5030	C	1,667	175	2nd Sqd.	30 Oct 93
HOW-	M109A2		C			2nd Sqd.	
HOW-	M109A2		C			2nd Sqd.	
H-13	M1A1	L130210	T	792	174	2nd Sqd.	07 Jul 93
H-23	M1A1	L13011	T	847	198	2nd Sqd.	08 Jul 93
H-33	M1A1	L12523	T	956	184	2nd Sqd.	08 Jul 93
H-12	M1A1	L12527	C	841	173	2nd Sqd.	07 Jul 93
H-22	M1A1	L13028	C	797	163	2nd Sqd.	07 Jul 93
H-32	M1A1	L13009	C	897	184	2nd Sqd.	07 Jul 93
HOW-11	M109A2	4910	T	2,995	296	1st Sqd.	10 Aug 93
HOW-12	M109A2	4887	T	1,837	325	1st Sqd.	11 Aug 93
HOW-13	M109A2	2895	T	1,821	376	1st Sqd.	11 Aug 93
HOW-17	M109A2	5477	C	851	100	1st Sqd.	13 Aug 93
HOW-16	M109A2	2899	C	4,361	351	1st Sqd.	12 Aug 93
D-14	M1A1	L13071	T	1,063	159	1st Sqd.	16 Aug 93
D-24	M1A1	L13045	T	1,086	177	1st Sqd.	17 Aug 93
D-34	M1A1	L13073	T	1,376	790	1st Sqd.	18 Aug 93
D-12	M1A1	L13062	C	1,247	191	1st Sqd.	16 Aug 93
D-22	M1A1	L13075	C	1,104	181	1st Sqd.	18 Aug 93
D-32	M1A1	L13037	C	1,190	187	1st Sqd.	17 Aug 93

TABLE 11. Test Hydraulic Fluid Requirements

	MIL-H-46170	MIL-H-6083	SHF (Proposed)
Pour Point, D 97, °C	–54 min	–59 min	–60 min
Viscosity, D 455, as follows:			
40°C, cSt	19.5 max	13 min	8 min
100°C, cSt	3.4 min	NR*	2.5 min
–40°C, cSt	2,600 max	800 max	800 max
Acid Number, D 664, mg KOH/g	0.20 max	0.20 max	Report
Flash Point, D 92, °C	204 min	82 min	180 min
Fire Point, D 92, °C	246 max	NR	190 min
Water Content, D 1744, wt%	0.05 max	0.05 max	0.01 max

* NR = Not Required

reservoirs, cylinders, and main gun recoil cylinders by disconnecting selected hydraulic lines as specified in Technical Manual (TM) 9-2350-303-20. Reservoirs, hydraulic cylinders, and lines were thoroughly purged and bled. The hydraulic systems were filled with SHF and pressurized. After a warm-up period, the hydraulic systems were again exercised. The drain process was repeated a second time to completely flush the systems of MIL-H-6083 OHT fluid. After the final fill, main gun cylinder pin adjustments were performed as specified in the TM. No components or seals were changed during the conversion procedure.

b. <u>M1A1 Main Battle Tanks</u>

The vehicles were warmed up, and the hydraulic systems were exercised. The systems were depressurized and the hydraulic fluid was drained from the main reservoirs by disconnecting the hydraulic line, which normally supplies fluid to the ammunition door actuator, and by using the on-board auxiliary pump to drain the fluid. The fluid in the main gun reservoirs was drained by removing the drain plug at the bottom of the recoil reservoir. The hydraulic systems were filled with SHF, purged, and exercised for 10 to 15 minutes. The systems were again drained and filled with SHF. No components or seals were changed during the conversion procedure.

4. Hydraulic Function Tests

Timed tests in seconds were performed on the M1A1 and M109A2 vehicles by timing the gun elevation and turret rotation in both directions. The timed tests were performed before and after the SHF conversion. The same tests were performed on the control vehicles. Additionally, on the M109A2 control vehicles, timed tests were performed before and after a system's fluid bleed, purge, and main gun cylinder pin adjustment. Turret rotation and gun elevation times improved significantly on the M109A2; however, it is believed that the improvement is due to the thorough purging and adjustments of the hydraulic systems and not the conversion to SHF. There were no significant time differences before or after conversion to SHF on the M1A1 vehicle. TABLE 12 shows the averaged results of the timed hydraulic function tests.

5. Sampling and Analysis

Hydraulic samples were obtained from the control vehicles and from the test vehicles before and after fluid conversion. The hydraulic systems were exercised and subjected to a warm-up period to ensure a homogenous sample. Analysis protocol was coordinated with Belvoir RD&E Center, and the analyses were performed by BFLRF personnel. TABLES 13 through 20 show the analyses results of samples obtained from test and control vehicles. It is interesting to note that there does appear to be some carry-over effects after the vehicles were flushed and filled with SHF. For instance, the M-1s that are serviced with MIL-H-46170 show higher viscosities and flashpoints than the fluid samples taken from M-109s that are serviced with MIL-H-6083. These results will be monitored.

TABLE 12. Timed Function Test Results on 3rd ACR Vehicles Participating in the SHF Demonstration Program at Ft. Bliss, TX (Initial Testing)

				Before Changeover/Purge Average Time (sec) to:				After Changeover/Purge Average Time (sec) to:			
				Elevation (max)		Rotation (360°)		Elevation (max)		Rotation (360°)	
Vehicle No.	Vehicle Type	Test (T) or Control (C)	Unit	Up	Down	c.w.*	c.c.w.†	Up	Down	c.w.	c.c.w.
HOW-12	M109A2	T	2nd Sqd.	15.38	14.72	22.24	22.00	15.31	12.37	22.39	21.09
HOW-15	M109A2	T	2nd Sqd.	16.91	31.98	23.00	22.62	16.52	12.60	21.75	21.24
HOW-16	M109A2	T	2nd Sqd.	28.61	10.71	25.27	25.22	17.48	12.03	24.05	24.25
HOW-13	M109A2	C	2nd Sqd.	15.36	10.65	21.63	21.36	12.85	12.81	21.79	21.54
H-13	M1A1	T	2nd Sqd.	0.86	0.43	9.79	9.72	0.68	0.63	9.67	9.38
H-23	M1A1	T	2nd Sqd.	0.78	0.80	9.63	9.53	0.88	0.76	9.59	9.42
H-33	M1A1	T	2nd Sqd.	1.12	0.79	9.78	9.69	0.79	0.70	9.45	9.36
H-12	M1A1	C	2nd Sqd.	1.05	0.88	9.53	11.23	NA**	NA	NA	NA
H-22	M1A1	C	2nd Sqd.	0.97	0.98	10.24	9.44	NA	NA	NA	NA
H-32	M1A1	C	2nd Sqd.	1.07	0.75	9.59	9.38	NA	NA	NA	NA
HOW-11	M109A2	T	1st Sqd.	18.45	12.06	22.97	23.67	16.04	12.39	20.88	20.78
HOW-12	M109A2	T	1st Sqd.	15.36	12.18	24.60	23.31	12.16	12.69	23.22	23.39
HOW-13	M109A2	T	1st Sqd.	20.86	12.24	23.20	22.67	15.22	12.81	21.57	21.25
HOW-16	M109A2	C	1st Sqd.	16.42	13.51	25.03	25.09	ND‡	ND	ND	ND
HOW-17	M109A2	C	1st Sqd.	15.29	14.62	22.66	22.57	15.01	13.97	22.24	22.44
D-14	M1A1	T	1st Sqd.	0.77	0.71	9.94	9.47	0.81	0.67	9.42	9.30
D-24	M1A1	T	1st Sqd.	0.75	0.62	9.65	9.43	0.73	0.68	9.36	9.40
D-34	M1A1	T	1st Sqd.	0.70	0.65	9.60	9.56	0.74	0.66	9.30	9.40
D-12	M1A1	C	1st Sqd.	0.82	0.75	9.82	9.59	NA	NA	NA	NA
D-22	M1A1	C	1st Sqd.	0.84	0.68	9.88	9.87	NA	NA	NA	NA
D-32	M1A1	C	1st Sqd.	0.77	0.59	9.63	9.53	NA	NA	NA	NA

* c.w. = Clockwise
† c.c.w. = Counterclockwise
** NA = Not Applicable
‡ ND = Not Determined

TABLE 13. 1/3 ACR M109A2 Howitzer Test and Control Vehicles Before Changeover

	MIL-H-6083 Requirements	AL-20506X How-11 (Test)	AL-20508X How-12 (Test)	AL-20507X How-13 (Test)	AL-20512X How-15 (Control)	AL-20513X How-16 (Control)
Pour Point, D 97, °C	–59 min	–58	<–57	<–57	<–60	<–57
Viscosity, D 455, as follows:						
40°C, cSt	13 min	13.74	13.75	13.92	13.74	14.23
100°C, cSt	NR*	4.76	4.86	4.67	4.66	5.05
–40°C, cSt	800 max	601	569	769	715	574
Acid Number, D 664, mg KOH/g	0.20 max	0.13	0.14	0.13	0.14	0.14
Flash Point, D 92, °C	82 min	104	110	113	110	104
Fire Point, D 92, °C	NR	113	116	118	121	116
Water Content, D 1744, wt%	0.05 max	0.06	0.10	0.03	0.03	0.05

* NR = Not Required

TABLE 14. 1/3 ACR M109A2 Howitzer Test Vehicles After Changeover

	SHF Proposed Requirements	AL-20510X How-11 (Test)	AL-20511X How-12 (Test)	AL-20509X How-13 (Test)
Pour Point, D 97, °C	−60 min	<−57	<−57	<−57
Viscosity, D 455, as follows:				
40°C, cSt	8 min	9.45	9.40	9.43
100°C, cSt	2.5 min	2.72	2.71	2.71
−40°C, cSt	800 max	731	734	744
Acid Number, D 664, mg KOH/g	Report	0.19	0.22	0.19
Flash Point, D 92, °C	180 min	166	174	177
Fire Point, D 92, °C	190 min	188	193	193
Water Content, D 1744, wt%	0.01 max	0.02	0.02	0.02

TABLE 15. 1/3 ACR M1A1 Abrams Tank Test and Control Vehicles Before Changeover

	MIL-H-46170 Requirements	AL-20524X D-14 (Test)	AL-20523X D-24 (Test)	AL-20525X D-34 (Test)	AL-20530X D-12 (Control)	AL-20531X D-22 (Control)	AL-20529X D-32 (Control)
Pour Point, D 97, °C	−54 min	<−56	<−56	<−56	<−56	<−56	<−56
Viscosity, D 455, as follows:							
40°C, cSt	19.5 max	15.90	15.81	15.84	15.81	15.86	15.85
100°C, cSt	3.4 min	3.75	3.85	3.74	3.74	3.87	3.75
−40°C, cSt	2600 max	2533	2515	2518	2517	2553	2520
Acid Number, D 664, mg KOH/g	0.20 max	0.13	0.11	0.11	0.13	0.14	0.11
Flash Point, D 92, °C	204 min	227	221	227	224	224	224
Fire Point, D 92, °C	246 max	246	254	252	252	252	249
Water Content, D 1744, wt%	0.05 max	0.05	0.05	0.05	0.05	0.05	0.03

TABLE 16. 1/3 M1A1 Abrams Tank Test Vehicles After Changeover

	SHF Proposed Requirements	AL-20527X D-14 (Test)	AL-20526X D-24 (Test)	AL-20528X D-24 (Test)
Pour Point, D 97, °C	-60 min	<-56	<-59	<-57
Viscosity, D 455, as follows:				
40°C, cSt	8 min	9.96	9.83	9.96
100°C, cSt	2 5 min	2.76	2.83	2.77
-40°C, cSt	800 max	867	847	874
Acid Number, D 664, mg KOH/g	Report	0.25	0.28	0.25
Flash Point, D 92, °C	180 min	191	185	182
Fire Point, D 92, °C	190 min	204	202	202
Water Content, D 1744, wt%	0.01 max	0.02	0.02	0.02

TABLE 17. 2/3 ACR M109A2 Howitzer Vehicles Before Changeover

	MIL-H-6083 Requirements	AL-20407X How-15 (Test)	AL-20409X How-16 (Test)	AL-20709X How-13 (Control)
Pour Point, D 97, °C	-59 min	<-50	<-50	<-54
Viscosity, D 455, as follows:				
40°C, cSt	13 min	13.65	13.35	13.37
100°C, cSt	NR*	4.81	4.47	4.51
-40°C, cSt	800 max	573	758	726
Acid Number, D 664, mg KOH/g	0.20 max	0.07	0.07	0.13
Flash Point, D 92, °C	82 min	108	111	107
Fire Point, D 92, °C	NR	116	116	124
Water Content, D 1744, wt%	0.05 max	0.02	0.02	0.05

* NR = Not Required

TABLE 18. 2/3 M109A2 Howitzer Test Vehicles After Changeover

	SHF Proposed Requirements	AL-20406X How-12 (Test)	AL-20408X How-15 (Test)	AL-20410X How-16 (Test)
Pour Point, D 97, °C	−60 min	<−54	<−54	<−47
Viscosity, D 455, as follows:				
40°C, cSt	8 min	9.37	9.46	9.42
100°C, cSt	2.5 min	2.73	2.74	2.72
−40°C, cSt	800 max	718	723	733
Acid Number, D 664, mg KOH/g	Report	0.42	0.42	0.37
Flash Point, D 92, °C	180 min	183	169	172
Fire Point, D 92, °C	190 min	191	177	191
Water Content, D 1744, wt%	0.01 max	0.02	0.02	0.02

TABLE 19. 2/3 ACR M1A1 Abrams Tank Test Vehicles Before Changeover

	MIL-H-46170 Requirements	AL-20418X H-13 (Test)	AL-20421X H-23 (Test)	AL-20419X H-33 (Test)	AL-20422X H-12 (Control)	AL-20415X H-22 (Control)	AL-20414X H-32 (Control)
Pour Point, D 97, °C	–54 min	<–54	<–54	<–54	<–54	<–54	<–54
Viscosity, D 455, as follows:							
40°C, cSt	19.5 max	15.71	14.89	15.78	15.11	15.78	15.71
100°C, cSt	3.4 min	3.73	3.60	2.76	3.62	3.71	3.74
–40°C, cSt	2600 max	2439	2187	2458	2249	2454	2452
Acid Number, D 664, mg KOH/g	0.20 max	0.11	0.10	0.12	0.08	0.11	0.11
Flash Point, D 92, °C	204 min	224	224	229	224	230	NES*
Fire Point, D 92, °C	246 max	248	248	252	248	248	NES
Water Content, D 1744, wt%	0.05 max	0.05	0.03	0.05	0.03	0.05	0.06

* NES = Not Enough Sample

TABLE 20. 2/3 ACR M1A1 Abrams Tank Test Vehicles After Changeover

	SHF Proposed Requirements	AL-20416X H-13 (Test)	AL-20420X H-23 (Test)	AL-20417X H-33 (Test)
Pour Point, D 97, °C	−60 min	<−47	<−54	<−54
Viscosity, D 455, as follows:				
40°C, cSt	8 min	9.80	9.83	9.88
100°C, cSt	2.5 min	2.75	2.75	2.77
−40°C, cSt	800 max	830	836	849
Acid Number, D 664, mg KOH/g	Report	0.30	0.34	0.34
Flash Point, D 92, °C	180 min	186	188	183
Fire Point, D 92, °C	190 min	199	202	205
Water Content, D 1744, wt%	0.01 max	0.01	0.02	0.02

6. Live-Fire Exercises

All test vehicles converted to the SHF with the exception of one M109A2 howitzer (How-12, 2/3 ACR) underwent live-fire exercises. How-12 did not fire due to problems with the M45 gun mount (not a hydraulic fluid-related problem). 1st Howitzer Battery, 1/3 ACR, 2nd Howitzer Battery and H Company, 2/3 ACR, conducted live firing at Dona Ana Range, NM, while D Company, 1/3 ACR, conducted live firing at the National Training Center at Ft. Irwin, CA, during annual training exercises. The howitzers fired an assortment of high-explosive (HE), HE practice, and illumination rounds while the tanks fired a combination of target practice SABOT and high- explosive anti-tank (HEAT) rounds. After the live-fire exercises, howitzer and tank crews were interviewed on the performance of the hydraulic systems, i.e., turret rotation, main gun elevation, ammunition door operation, and moving target tracking (M1A1). No differences between OHT, FRH, and SHF fluids were reported. Also, no visible leaks were reported in any of the systems. TABLES 21 and 22 show the type and number of rounds fired from test and control vehicles.

TABLE 21. Live Rounds Fired by M109A2 Howitzer Test and Control Vehicles

Fluid Type	Vehicle No.	Unit	Type of Ammunition		
			HE	HE Practice	Illumination
SHF	How-11	1st Squadron	45		14
SHF	How-12	1st Squadron	49		16
SHF	How-13	1st Squadron	47		12
OHT	How-15	1st Squadron	40		6
OHT	How-16	1st Squadron	46		2
OHT	How-17	1st Squadron	40		5
SHF	How-12	2nd Squadron	Not Fired		
SHF	How-15	2nd Squadron	22	33	
SHF	How-16	2nd Squadron	36	39	46
OHT	How-11	2nd Squadron	6	38	
OHT	How-13	2nd Squadron	48	73	
OHT	How-14	2nd Squadron	Not Fired		

TABLE 22. Live Rounds Fired by M1A1 Abrams Tank Test and Control Vehicles

Fluid Type	Vehicle No.	Unit	Type of Ammunition	
			SABOT (Target Practice)	HEAT
SHF	D-14	1st Squadron	45	8
SHF	D-24	1st Squadron	42	8
SHF	D-34	1st Squadron	40	9
FRH	D-12	1st Squadron	36	6
FRH	D-22	1st Squadron	43	8
FRH	D-32	1st Squadron	44	6
SHF	H-13	2nd Squadron	42	10
SHF	H-23	2nd Squadron	39	9
SHF	H-33	2nd Squadron	41	12
FRH	H-12	2nd Squadron	40	8
FRH	H-24	2nd Squadron	41	7
FRH	H-34	2nd Squadron	38	6

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the comparative results reported, it appears that the flammability hazard would not be significantly increased if SHF were used to replace the specification MIL-H-46170 hydraulic fluid in armored ground equipment. Although the flash point is lower than MIL-H-46170, this shortcoming was not reflected in any other aspect of the flammability evaluations. In fact, the longstanding shortcoming of MIL-H-46170, that of lower hot-surface ignition temperatures, seemed to be improved with this proposed fluid modification. Probably the most important factor in considering use of the lower viscosity candidate fluids should be based on the results of the ballistic tests, which are considered to be very severe exposure. Those results did indicate that the fluid's response to ballistic impact was more similar to MIL-H-46170, giving reduced residual burning, than that experienced with the more volatile MIL-H-6083 fluids.

Results obtained from the pilot field demonstration have been extremely encouraging with no real problems identified after several months of operation in the armored vehicles. Concerns over leakage and seal integrity have failed to materialize, and performance during firing exercises has failed to identify any shortcomings when the fluid is tested under moderate to hot environments.

The M109 systems, having first used MIL-H-6083 (petroleum base), may be expected to experience seal weepage after long-term exposure to the synthetic-base SHF candidates. However, it would not be expected that the M1A1 systems would experience increased seal weepage, since the M1A1s had been using the MIL-H-46170 (similar synthetic base) prior to installation of the SHF. After completion of the pilot field demonstration, more firm conclusions and recommendations will become evident.

V. LIST OF REFERENCES

1. Military Specification MIL-H-46170B, Hydraulic Fluid, Rust Inhibited, Fire Resistant, Synthetic Hydrocarbon Base, 18 August 1982.

2. Military Specification MIL-H-6083E, Hydraulic Fluid, Petroleum Base, for Preservation and Operation, 14 August 1986.

3. Military Specification MIL-H-83282C, Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft, NATO Code No. H-537, 25 March 1986.

4. Federal Test Method Standard No. 791C, Lubricants, Liquid Fuels, and Related Products; Methods of Testing, 30 September 1986.

5. Wright, B.R., et al., "A Technique for Evaluating Fuel and Hydraulic Fluid Ballistic Vulnerability," Interim Report AFLRL No. 89 (AD A055058), prepared by U.S. Army Fuels and Lubricants Research Laboratory, San Antonio, TX, December 1977.

6. Wright, B.R., "Trade-Off Assessment of Candidate Fire-Resistant Hydraulic Fluids," Letter Report No. BFLRF-90-001, prepared by U.S. Army Fuels and Lubricants Research Facility, San Antonio, TX, March 1990.

APPENDIX A

ASTM D 2882 Test Results
MIL-H-6083 Single Hydraulic Fluid

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

Fluid Code: AL-21162-X

Pressure: 2000 psi

Date: December 15, 1993

Temperature: 65°C

Run Number: WV-2-10-186

WEIGHT LOSS, mg

176.6882 g Before	Weight of Ring	176.6846 g After	Weight Loss:	3.6 mg
34.7686 g Before	Weight of Vanes	34.7685 g After	Weight Loss:	0.1 mg

Total Weight Loss: 3.7 mg
Spec. Limit: 10.0 mg

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

SUPPLEMENTAL OPERATIONAL DATA

REMARKS

This test was shutdown at 2 hours because the fluid flow dropped below the acceptable limits and the temperature of the fluid could not be controlled.

APPENDIX B

ASTM D 2882 Test Results
Test Fluid B Single Hydraulic Fluid

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

Fluid Code: AL-20405X

Pressure: 2000 psi

Date: December 11, 1993

Temperature: 65°C

Run Number: WV-2-9-185

WEIGHT LOSS, mg

180.7957 g Before	Weight of Ring	180.7868 g After	Weight Loss:	8.9	mg
34.7560 g Before	Weight of Vanes	34.7550 g After	Weight Loss:	1.0	mg

Total Weight Loss: 9.9 mg

Spec. Limit: 10.0 mg

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

SUPPLEMENTAL OPERATIONAL DATA

REMARKS

This test was shutdown at 1 hour because the fluid flow dropped below the acceptable limits and the temperature of the fluid could not be controlled.

APPENDIX C

ASTM D 2882 Test Results
MIL-H-46170 Single Hydraulic Fluid

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

Fluid Code: AL-21161-X

Date: December 15, 1993

Run Number: WV-3-7-166

Pressure: 2000 psi

Temperature: 65°C

WEIGHT LOSS, mg

177.3038 g Before	Weight of Ring	177.3039 g After	Weight Loss:	+0.1 mg
34.7834 g Before	Weight of Vanes	34.7834 g After	Weight Loss:	0.0 mg

Total Weight Loss: +0.1 mg
Spec. Limit: 10.0 mg

SOUTHWEST RESEARCH INSTITUTE

ASTM D 2882 VICKERS VANE PUMP WEAR TEST

SUPPLEMENTAL OPERATIONAL DATA

REMARKS

This test was shutdown at 2 hours because the fluid flow dropped below the acceptable limits and the temperature of the fluid could not be controlled.

APPENDIX D

Single Hydraulic Fluid Pilot Field Demonstration Plan for Ft. Bliss, TX

SINGLE HYDRAULIC FLUID PILOT
FIELD DEMONSTRATION PLAN
FOR
FT. BLISS, TX

I. PURPOSE

The purpose of this plan is to demonstrate acceptable field performance of combat tracked vehicles using the new single hydraulic fluid (SHF) that was developed to replace MIL-H-6083 and MIL-H-46170 fluids.

This fluid has better flammability properties than MIL-H-6083 and will perform better at low temperatures than MIL-H-46170.

II. OBJECTIVE

The objective is to measure the performance of SHF relative to the performance of petroleum-base MIL-H-6083 and synthetic-base MIL-H-46170 fire-resistant hydraulic fluids. The performance will be measured in tracked combat vehicles' hydraulic systems by monitoring:

- Selected test vehicles operating on SHF and selected control vehicles operating on conventional hydraulic fluid;
- Hours of operation of both test and control vehicles;
- Results of periodic hydraulic fluid sampling and analysis;
- System performance inspections as specified in applicable technical manuals.

III. SCOPE

A pilot normal mission/training nonimpact field evaluation to demonstrate the acceptability of a newly developed single hydraulic fluid will be conducted at Ft. Bliss, TX, on the following types of vehicles:

- M1A1 Main Battle Tank
- M109A2 Self-Propelled Howitzer

The U.S. Army 3rd Armored Cavalry Regiment (ACR) has agreed to support field evaluations of the newly developed single hydraulic fluid. Point of contact is CPT Virgil Williams, Regimental Maintenance Management Officer, Ft. Bliss, TX, 79916-5000, Telephone: Autovon 784-6400, Commercial (915) 568-6400.

U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RD&E Center) has overall program responsibility. Point of contact is Mr. M.E. LePera, Chief, Fuels and Lubricants Division, Logistics Equipment Directorate, Ft. Belvoir, VA, 22060-5606, Telephone: Autovon 354-3435, Commercial (703) 704-1819.

Belvoir Fuels and Lubricants Research Facility (SwRI) (BFLRF) will conduct the field evaluation and will furnish the necessary test equipment and the test single hydraulic fluid. Point of contact is Mr. Ruben Alvarez, Belvoir Fuels and Lubricants Research Facility, c/o Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX, 78228-0510, Telephone: Commercial (210) 522-3264.

The Deputy Director for Logistics, Directorate of Installation Support (ATZC-ISL) and the U.S. Army Materiel Command Logistics Assistance Office (AMXLA-C-C-BL) at Ft. Bliss, will be notified of omissions or additions in the scope of the field demonstration plan. Copies of correspondence, interim, and final reports will be provided to these activities.

IV. RESPONSIBILITIES

A. 3rd ACR

Responsibilities of the 3rd ACR are as follows:

- Furnish task units that will provide the test and control vehicles and crews;
- Arrange coordination meetings between BFLRF staff and participating units.

The following vehicles are required for the demonstration:

Vehicle	Quantity	Hydraulic Fluid
M1A1	6	SHF
M1A1	6	MIL-H-46170
M109A2	6	SHF
M109A2	6	MIL-H-6083

B. BFLRF

Responsibilities of BFLRF are as follows:

- Provide technical support personnel to conduct the evaluations;
- Provide analytical equipment for chemical analysis;
- Provide test fluid to participating units;
- Coordinate shipment and storage of test fluid at Ft. Bliss;
- Prepare interim and final reports.

V. PERIOD OF EVALUATION

The evaluation will be conducted for a minimum of one year.

VI. PROCEDURE

A. Test Vehicle Preparation

1. The hydraulic systems of vehicles selected for evaluation, test and control, must be inspected to ensure that systems are fully operational.

2. The hydraulic systems of test and control vehicles will be drained, flushed, and filled with the appropriate hydraulic fluid as prescribed in applicable lubrication orders.

B. Data Requirements

BFLRF personnel will visit participating units on a quarterly basis to collect data and discuss problems, if any, with maintenance personnel and crews. The participating unit's point of contact will be notified prior to each visit. Data forms will be provided by BFLRF. The data will include but are not limited to the following:

1. Hours of operation;

2. Changes or additions of hydraulic fluid;

3. Hydraulic system malfunction, response, seal leakage, binding, etc.

Quarterly hydraulic fluid samples will be obtained by BFLRF personnel. Prior to withdrawing the samples, the system will be exercised for 15 minutes to allow the fluid to warm and to ensure a homogenous sample for analysis. The fluid level will be replenished to the normal "full" mark **after** sampling.

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ATTN: WL/MLSE 1
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